CALIBRATION AND EVALUATION OF AVIRIS DATA: CRIPPLE CREEK IN OCTOBER 1987

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ABSTRACT

Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) data were obtained over Cripple Creek and Canon City Colorado on October 19, 1987 at local noon. Multiple ground calibration sites were measured within both areas with a field spectrometer and samples were returned to the laboratory for more detailed spectral characterization. The data were used to calibrate the AVIRIS data to ground reflectance. Once calibrated, selected spectra in the image were extracted and examined, and the signal to noise performance was computed. Images of band depth selected to be diagnostic of the presence of certain minerals and vegetation were computed. The AVIRIS data were extremely noisy, but images showing the presence of goethite, kaolinite and lodgepole pine trees agree with ground checks of the area.

INTRODUCTION

As part the NASA Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) Investigators program, AVIRIS data were obtained over Cripple Creek and Canon City, Colorado, on October 19, 1987 at local noon. This paper describes analysis for Cripple Creek. The mineralogy of the Cripple Creek/Canon City area is varied and contains appropriate minerals for testing the spectral characteristics of AVIRIS. The region contains Tertiary volcanic rocks and Precambrian metamorphic and plutonic rocks, including areas of well-known alteration and mineralization. There are specific sites containing the minerals kaolinite, montmorillonite, gypsum, calcite, dolomite, jarosite, hematite, goethite, biotite, and muscovite that are large enough in extent to be resolved by AVIRIS. Exposures of rocks containing other OH-bearing minerals are also present.

The October 19th flight was the second to last of the AVIRIS flight season, and it was known that instrument performance had degraded somewhat (e.g. Vane and others, this volume). Our goal was to calibrate the AVIRIS data to ground reflectance (atmospheric absorptions and solar flux removed) and to use the calibrated data to evaluate mineral mapping capabilities. This initial investigation reports on 552 scan lines of AVIRIS data (614 pixels wide) centered on the towns of Cripple Creek and Victor, Colorado (Figure 1 and Slide No. 3).

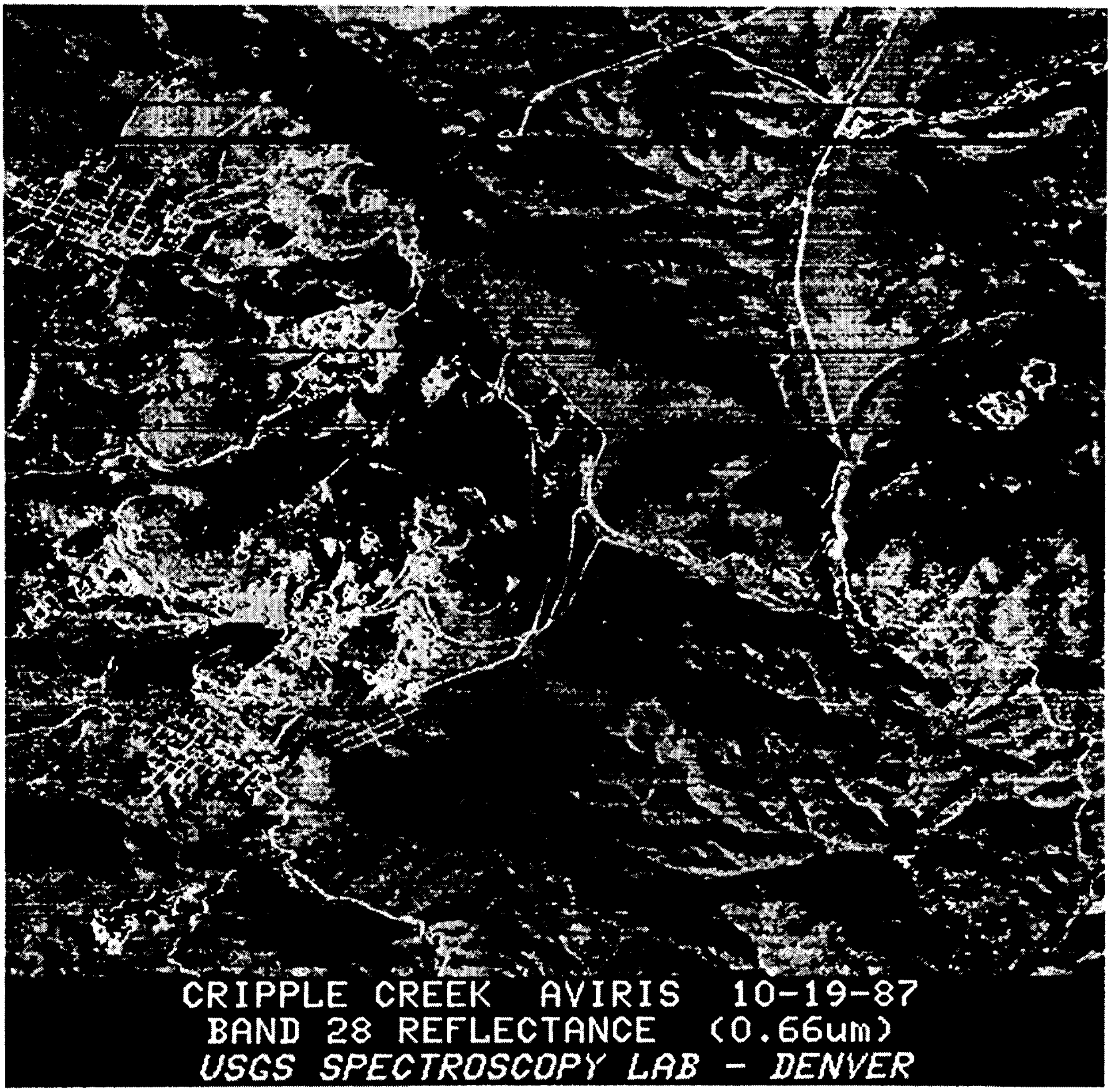

Figure 1. A visible reflectance image from channel 28 (0.66 μm) of the AVIRIS data over Cripple Creek, Colorado. The scene is 614 pixels wide by 552 lines long, covering an area of 11 by 10 km.

CALIBRATION

Two concerns about the standard JPL processing of the AVIRIS data (Reimer *et al.*, 1987) were addressed. First and foremost was the spectral interpolation to a uniformly spaced wavelength set. Second was the smoothing of variations in the dark signal by averaging 101 scan lines of dark data.

Spectral interpolation can cause apparent shifts in band position of up to ½ channel. In practice, such shifts would only be significant for the sharpest absorption bands. More importantly, interpolation of data that includes a bad channel would result in two bad channels. AVIRIS does have noisy channels (e.g. see Vane and others, this volume). For these reasons, and because our software, the SPECtrum Processing Routines (SPECPR) (Clark, 1980), handles any wavelength set with any spacing, we were able to process noninterpolated data. Another advantage to using SPECPR is that our spectral library, which is in SPECPR format, has been measured at a spectral resolution higher than that for AVIRIS and then convolved to the AVIRIS resolution and sampling interval. SPECPR is not an imaging system, however, so that once the spectral analysis is complete, images are extracted and moved to our standard image processing system for further analysis and display.

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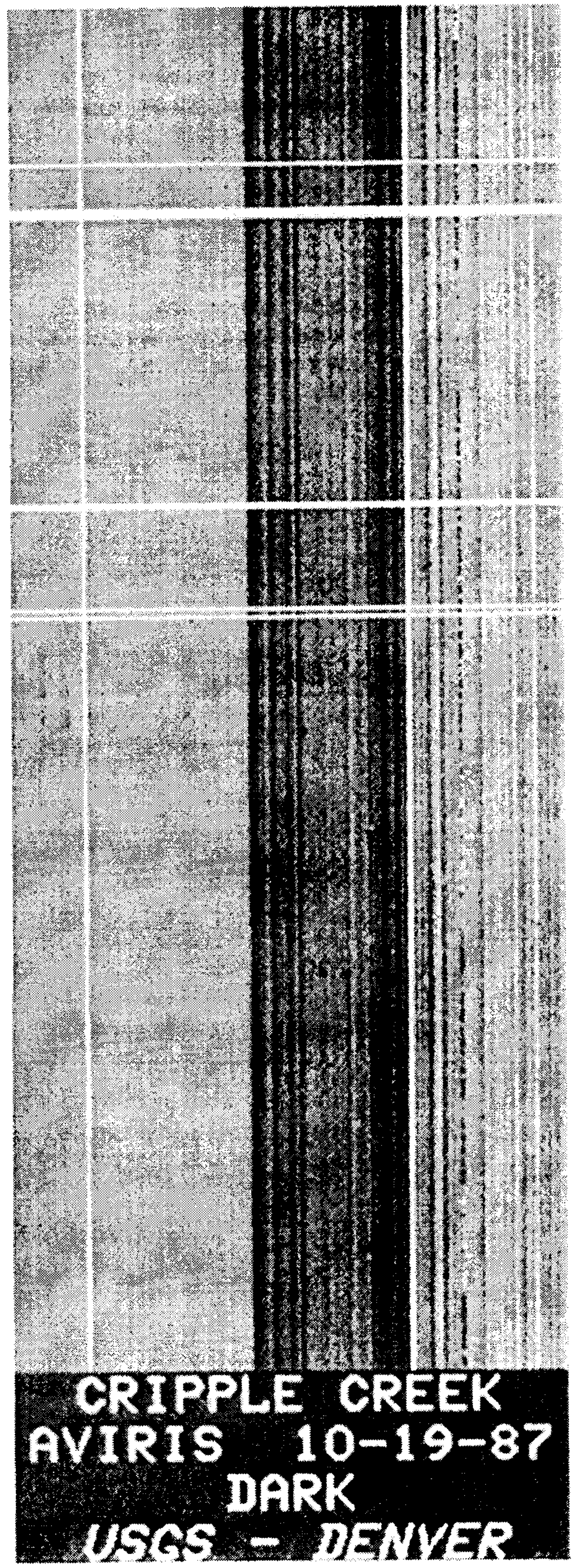

Figure 2. The image of the dark data from the scene in Figure 1. The image is 224 pixels across, corresponding to the 224 spectral channels and 552 lines long, corresponding to the 552 lines in Figure 1. The four vertical regions correspond to the four spectrometers in the AVIRIS instrument and wavelength increases from left to right. The white horizontal bands are dropped lines. The diagonal dark band in the center of the image is an artifact of photographic processing and is not in the dark data.

The raw Cripple Creek/Canon City data were first examined for general quality and for periodic noise. Other investigators (see other papers in this volume) had reported periodic noise in their data, but ours showed none (Figure 1). However, there appeared to be discontinuities in the raw image intensity level and scan line drop-outs. Upon further examination, it was discovered that the discontinuities also occur in the dark signal image (Figure 2). Therefore, it was decided to process the data from scratch because the standard JPL 101 scan line smoothing would have destroyed this information.

The dark image in Figure 2 appears to show some pattern, but Fourier analyses of each spectrometer show no clear frequency peaks; the bright and dark banding are random noise. A sample Fourier Transform of one channel is shown in Figure 3.

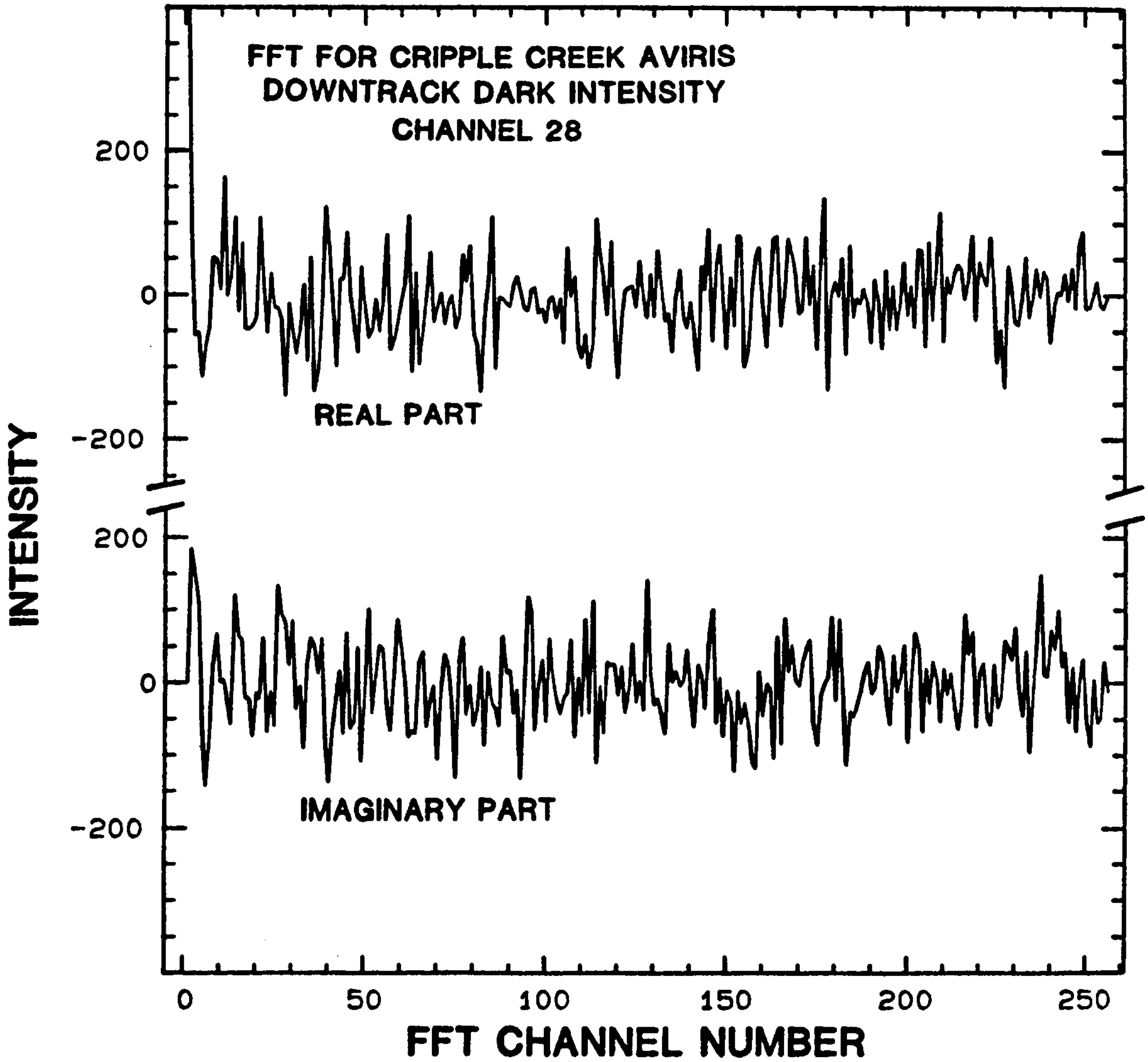

Figure 3. A Fourier Transform of channel 28 for 512 lines down the image in Figure 2. No periodic noise is evident.

Four ground calibration sites occur within the chosen 614 by 552 pixel data set. Samples were collected from each calibration site shortly after the flight for laboratory measurement. A field crew checked each site, verified pixel locations and identified uniform regions in the AVIRIS data within the calibration area. Laboratory reflectance spectra of samples collected within the calibration sites were convolved to AVIRIS raw data spectral resolution and sampling interval using SPECPR. Next, the corresponding AVIRIS raw spectral data, the JPL laboratory calibration data, and the dark spectra were extracted using SPECPR. The AVIRIS spectra were then dark corrected and calibration to ground reflectance, R, according to the following equation:

$$R = (DN - DK)\ CL\ CR, \qquad \text{eqn (1)}$$

where DN is the raw data number from the AVIRIS instrument at a given wavelength and pixel, DK is the dark measured once each scan line (one spectrum), CL is the JPL lab calibration (Vane *et al.*, 1987), and CR is the correction to convert the AVIRIS data to ground reflectance. Equation 1 is applied to each spectral channel in a pixel independently. The CL multiplier is necessary to correct the data for crosstrack vignetting (Vane *et al.*, 1987) and consists of 614 spectra, one for each crosstrack pixel. If there were no vignetting, the CL multiplier could be dropped from the equation. In practice, the CL correction amounts to only a few percent at the edges of the scan line relative to the center. The CR multiplier spectrum is an average of several pixels from each of the calibration sites. The laboratory calibration data are averages of two to four spectra from each calibration site.

Because of the use of ground calibration sites the calibration procedure in equation 1 corrects for any instrument response, solar irradiation function, and atmospheric transmission. The procedure is simplistic in that it ignores light contribution from atmospheric scattering, and the correction specifically applies to one elevation at a certain scan angle. In practice, the Cripple Creek area has significant topography, and while the atmospheric correction is only approximate, the small differential atmospheric paths can cause only minor inaccuracies. For the quality of this data set, no adverse effects could be detected.

Atmospheric scattering is negligible in this data set. Spectra of the lake in the lower right corner of the image have reflectance levels less than 1% at wavelengths greater than 1.3 μm, no more than about 2% from 0.7 to 1.3 μm, and a maximum of 8% at shorter wavelengths where there is likely scattering in the lake itself.

It is our intent in the future to use a digital elevation model to derive the correction factors as a function of elevation and scan angle, and to apply that function to each pixel so that all atmospheric features are properly removed. The problem is analogous to astronomical extinction corrections now commonly applied throughout the near infrared (e.g. McCord and Clark, 1979).

The calibrated reflectance image for channel 28 is shown in Figure 1. The image has a lot of scan line striping, at least in part due to no smoothing of the dark data. Discussions at the 1988 AVIRIS workshop at JPL showed considerable confusion about dark smoothing.

A dark spectrum is obtained by AVIRIS once each scan line. Thus if no smoothing is performed, the same dark spectrum is subtracted from 614 (crosstrack) spectra. If the dark data number for a particular channel was a little high (due to natural noise variations), then the dark subtracted channel for that whole scan line would tend to be low. A reasonable assumption from the way the AVIRIS instrument operates (e.g. Porter and Enmark, 1987) is that the noise level of the dark is equal to the noise level in an individual pixel. Examination of the Cripple Creek data shows that to be true. The following is a noise model of the system:

AVIRIS Pixel: DN $\pm \sigma_p$

AVIRIS Dark: DK $\pm \sigma_d$

AVIRIS Dark subtracted data: A = DN - DK

$$\text{Noise: } \sigma_a = (\sigma_p^2 + \sigma_d^2)^{1/2} \qquad \text{(eqn 2)}$$

If, as stated above, the noise in the dark equals the noise in the image data, then

$\sigma = \sigma_p = \sigma_d$, and

$$\sigma_a = \sqrt{2}\,\sigma \qquad \text{(eqn 3)}$$

The dark subtracted image has a noise only 1.41 times greater than the original image. Dark averaging can reduce this noise increase according to the formula:

$$\sigma_a = (\sigma_p^2 + (\sigma_d^2)/n)^{1/2} \qquad \text{(eqn 4)}$$

Table 1 shows the specific improvements in the signal to noise as a function of n.

Table 1
Noise of Dark Averaged and Subtracted Image
Relative to the Noise in Original Image

Number of Darks Averaged	Noise
1 (no smoothing)	1.41
4	1.12
8	1.06
12	1.04
101	1.005

From Table 1, it is clear that there is little to be gained beyond smoothing a few spectra. Alternatively, if too many lines are smoothed and the instrument changes (e.g. the dark level drifts), then a larger error could result. If the dark is averaged over too many scan lines, any drifts and jumps in the dark level will be averaged out. Figure 4 shows such an effect.

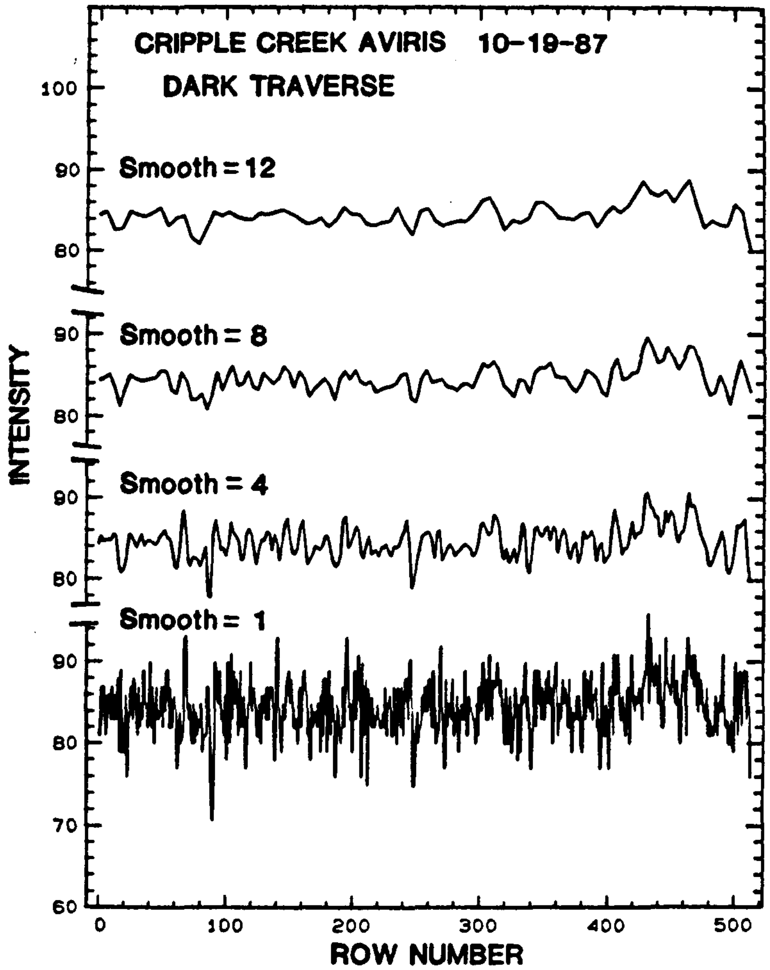

Figure 4. The dark value down the image for 512 lines is shown for channel 28 with different smoothing levels.

There is a rise in the dark level starting at about scan line 420. When the dark is smoothed by averaging adjacent lines, the boundary will become less of a step function, and significantly rounded at a smooth level of 12. The example shown is subtle, but the principles are clear. We recommend that the standard JPL processing be modified to so that the number of darks averaged is a variable that the user can specify in case the instrument is drifting.

In the process of calibrating the AVIRIS spectral data, it was decided to produce a data set whose channels were in increasing wavelength but sampled at the AVIRIS flight instrument wavelengths so no interpolation was done. In addition, each spectrometer has a small overlap region with adjacent spectrometers, and that overlap region was deleted. From the original 224 channel data, channels 31, 32, 33, 94, 95, 96, 97, 98, 160, 161, 162, and 163 were deleted so a 212 channel data set was produced. Finally, because the data are stored in 16-bit integers per pixel, the real data were scaled so that a reflectance of 1 is 20,000.

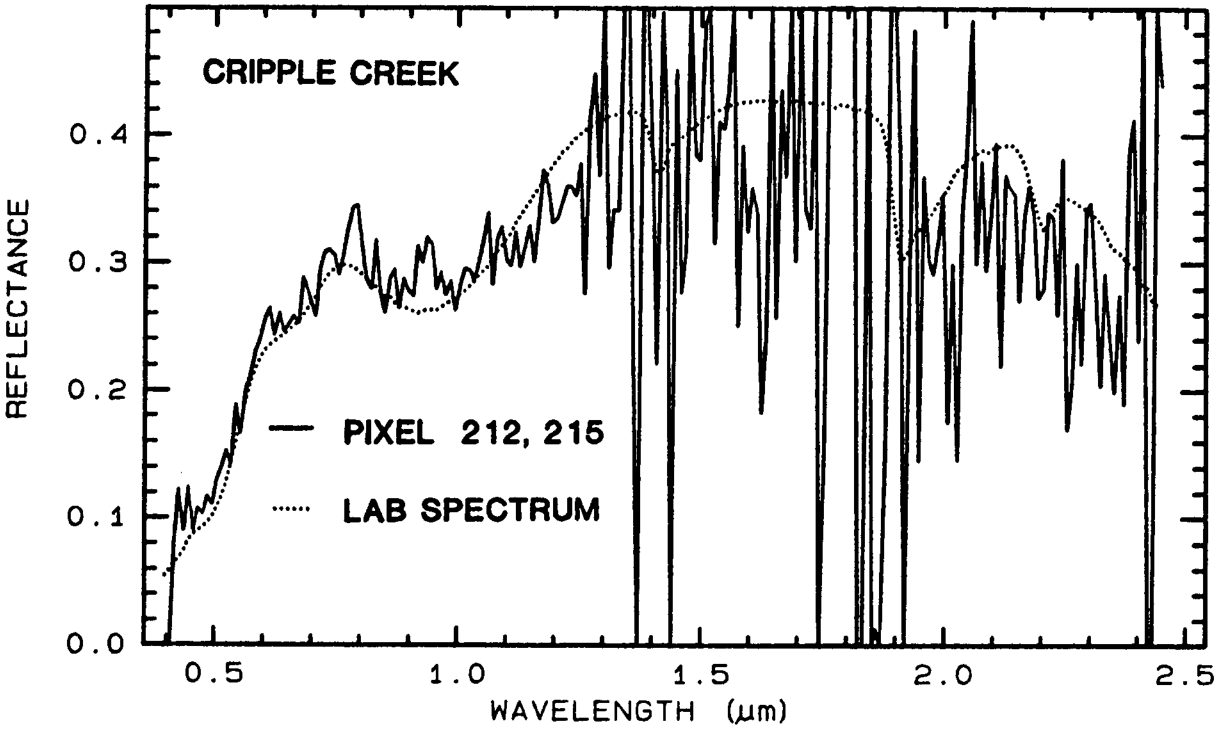

Figure 5. A sample AVIRIS spectrum (a single pixel at location scan line 212, pixel 215 in the image in Figure 1) is shown (solid line) compared to a laboratory spectrum convolved to the same spectral resolution and sampling interval (dotted line). The laboratory spectrum is of a representative soil sample from the area covered by the pixel. The general reflectance level and shape agrees well (within the noise). High noise is expected in the 1.4- and 1.9-μm regions because of absorption due to telluric water.

SPECTRAL ANALYSIS

The calibrated AVIRIS data set can be used to extract reflectance spectra for direct analysis. Figure 5 shows a sample spectrum extracted and a laboratory spectrum of representative material from the pixel location. Within the noise, the AVIRIS data agree with the laboratory data.

The signal-to-noise-ratio spectrum was derived by computing the standard deviation of 36 pixels in a uniform region of the small lake seen in the lower right corner of the image in Figure 1. That standard deviation was inverted and scaled to indicate the signal to noise expected from an individual pixel (Figure 6). It can be seen that the signal to noise is very poor, especially from 1.25 to 2.45 μm. Again dark smoothing would improve the data by about a factor of 1.4. If the data were obtained in June rather than late October, the signal would have been nearly a factor of two higher, so the signal to noise could potentially be as high as about 25 in the 2.2-μm region instead of about 9.

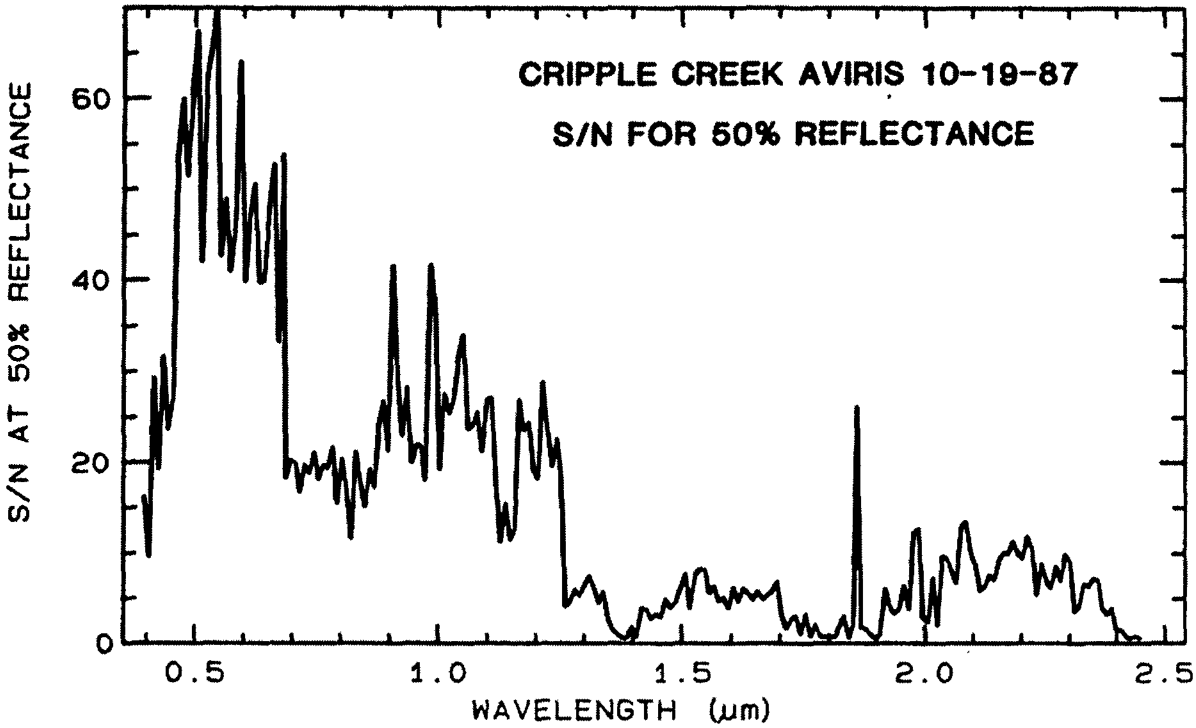

Figure 6. The signal to noise derived from the Cripple Creek AVIRIS data is shown relative to a constant reflectance of 50% at all wavelengths.

A simple spectral analysis was conducted to map specific absorption band depths in the image. Absorption bands were chosen for minerals and vegetation that are known or likely to be present in the Cripple Creek area. An absorption band was defined by two continuum channels and the channel closest to the absorption band center. The absorption band depth, D, is defined relative to its continuum, R_c and the reflectance at the band center, R_b (Clark and Roush, 1984):

$$D = 1 - R_b/R_c \qquad \text{(eqn 5)}$$

Band-depth images were computed for a number of minerals, including the 1.75-µm band of gypsum, the 1.27-µm band of biotite, the 2.34-µm band of calcite, the 2.32-µm band of dolomite, the 2.21-µm band of montmorillonite, the 2.20-µm band of kaolinite, the 0.45-µm and 0.93-µm bands of jarosite, the 0.85-µm band of hematite, and the 0.94-µm band of goethite. A band depth image for the 0.68-µm band of lodgepole pine was also computed. Because the visible data are much better than the near-IR, the band depths in the 1.25- to 2.45-µm spectral region show very little information (Figure 7). Absorptions in the visible show much more detail (Figure 8).

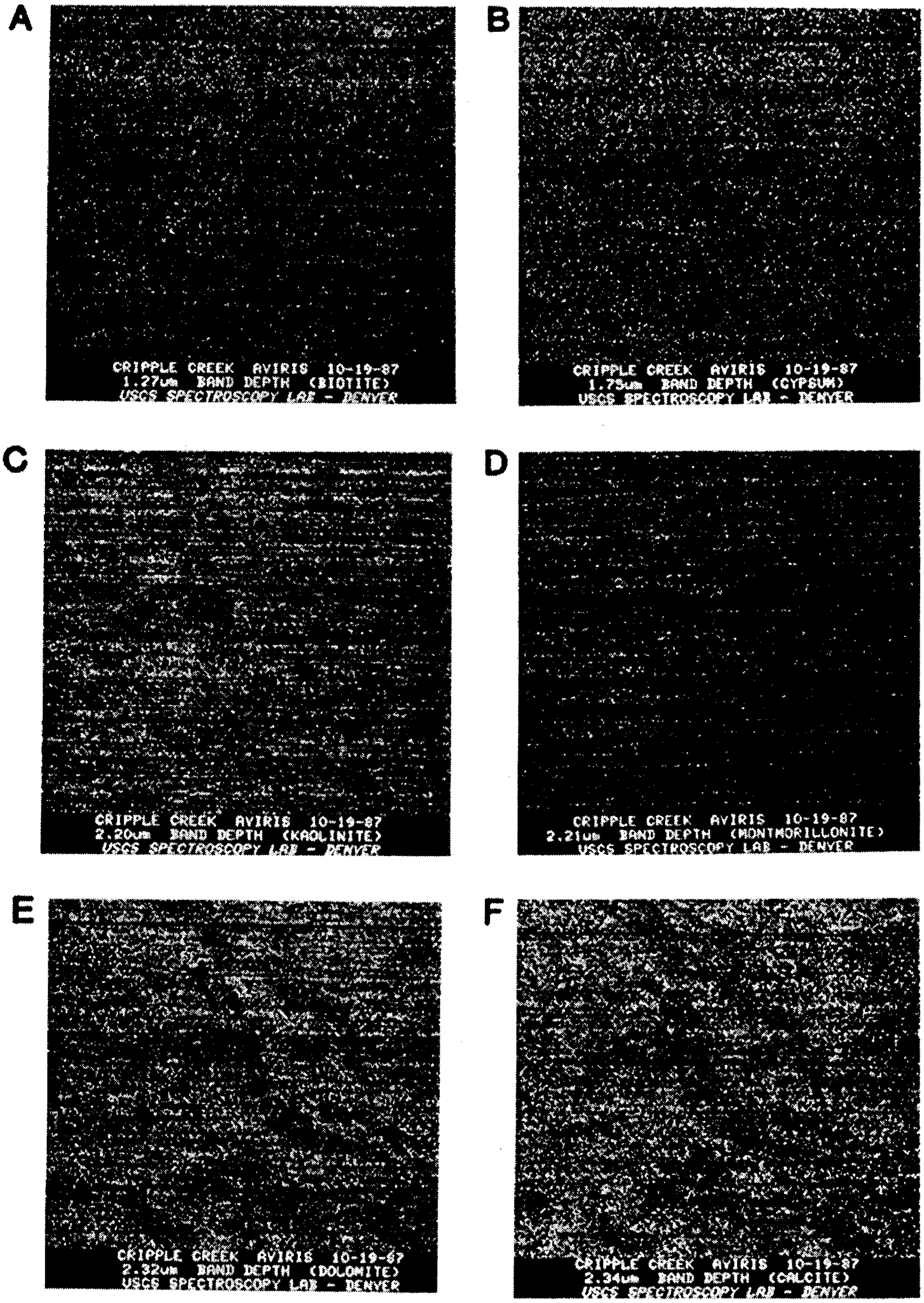

Figure 7. Band depth images of the Cripple Creek area: A) the 1.27-μm band of biotite, B) the 1.75-μm band of gypsum, C) the 2.20-μm band of kaolinite, D) the 2.21-μm band of montmorillonite, E) the 2.32-μm band of dolomite, and F) 2.34-μm band of calcite.

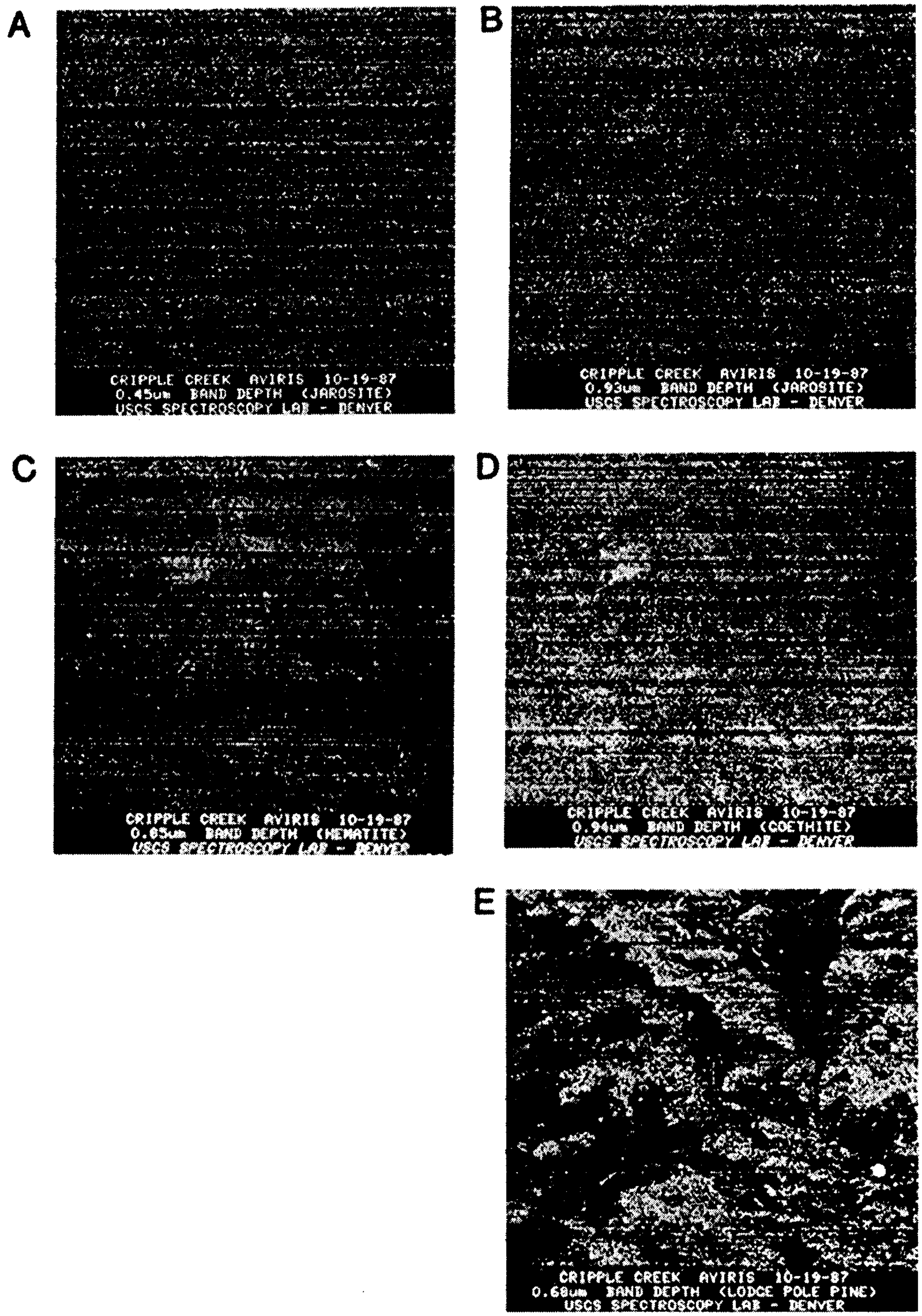

Figure 8. Band depth images of the Cripple Creek area: A) the 0.45-μm and B) 0.93-μm bands of jarosite, C) the 0.85-μm band of hematite, D) the 0.94-μm band of goethite, and E) the 0.68-μm band of lodgepole pine.

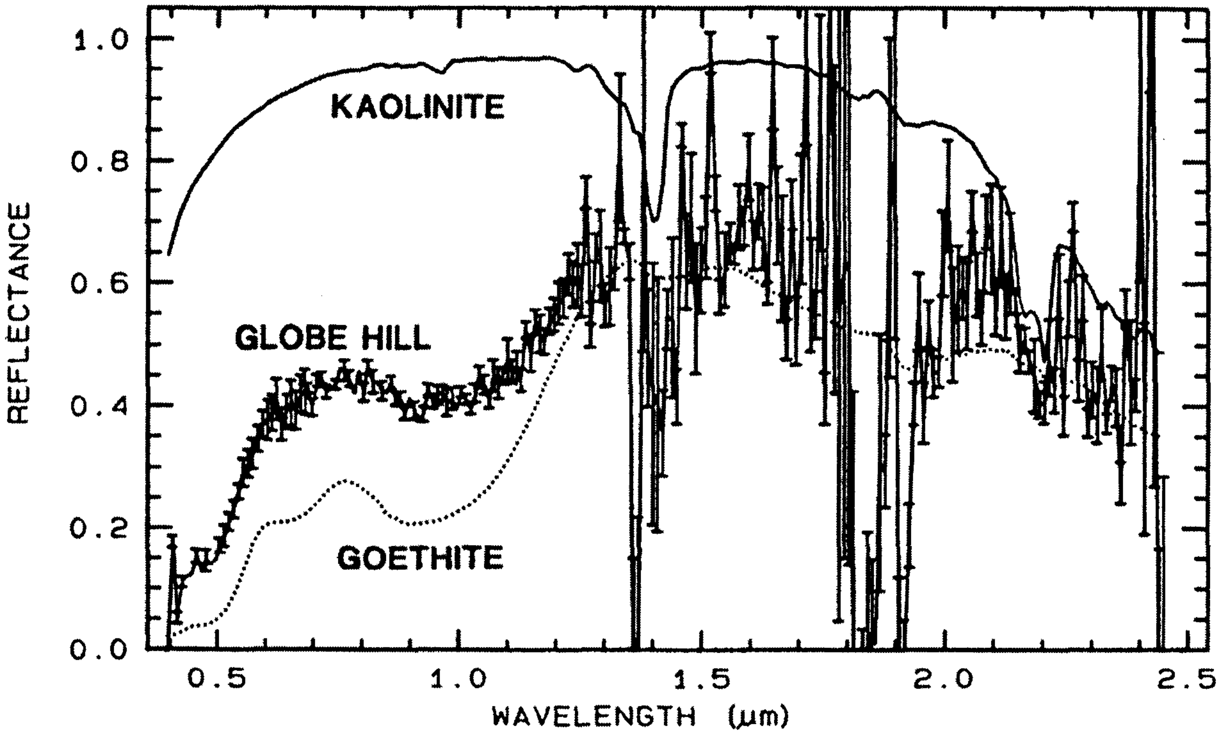

Figure 9. AVIRIS spectrum is shown for the Globe Hill area (average of 5 pixels: the spectrum with error bars) compared to spectrum library data convolved to the AVIRIS spectral resolution and sampling interval. The upper solid line is kaolinite and the lower dotted line is goethite.

Because of the 3-channel method of computing band depths, similar bands will show similar results. For example, the jarosite, hematite, and goethite 0.9-μm band images show similarities because the spectral features are broadly overlapping. Extracted spectra, however, show that the strongest absorption in the images (Globe Hill, to the upper left of center) is really goethite (Figure 9).

The kaolinite image also shows a weak signature indicating its presence in the Globe Hill area. A combination of the kaolinite, goethite, and lodgepole pine band depths were used to produce the Color-Composite-Band-Depth Image (CCBDI) shown in slide No. 4. The Globe Hill area shows a reddish-purple color indicating the presence of both kaolinite and goethite. Globe Hill is known to be a region of hydrothermal alteration and extracted spectra confirms this fact (Figure 9).

CONCLUSIONS

The AVIRIS data for the 1987 flight season in October is very noisy, but it is still possible to calibrate the data to ground reflectance. The calibration to reflectance allows absorption bands from specific minerals to be mapped. Areas of goethite, kaolinite and lodgepole pine were clearly mapped in the Cripple Creek area. The signal to noise must be substantially improved, however, if mapping of minerals is to be done where the absorptions are weak due to low abundance or partial vegetation cover.

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SLIDE CAPTIONS

Slide No. 3. A false-color-infrared composite of the Cripple Creek scene. The reflectance at 0.88 μm is red, the reflectance at 0.68 μm is green, and the reflectance at 0.54 μm is blue.

Slide No. 4. A Color-Composite-Band-Depth Image (CCBDI): the band depth for the 0.94-μm goethite band depth is assigned to red, the 0.68-μm lodgepole pine band depth is assigned to green, and the 2.20-μm kaolinite band depth is assigned to blue. A band depth of zero is black. The purplish area to the upper left of center is Globe Hill, a region of hydrothermal alteration.